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Effects of nutrition and irrigation on sweet pepper production in volcanic tuff

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Abstract

In this study aimed at increasing sustainability in soilless cultivation, volcanic tuff was used as substrate and the tested plant material was blocky type pepper (cv. 4-Ever F_1). Three experimental factors were evaluated: cultivation system (open or closed), nutrient composition (N_1, N_2, N_3, N_4) and irrigation frequency (I_1, I_2, I_3, I_4). Macro nutrient concentrations of N_2, N_3 and N_4 were 2-, 3- and 4-fold of N_1. Concentrations of micronutrients were the same for all treatments. Irrigation was started when indoor solar radiation reached 6, 4, 2 and 1 MJ m^{-2} in the treatments I_1, I_2, I_3 and I_4, respectively. As a sustainable soilless technique, closed system was found to be recommendable by incorporating the treatment $N_4 + I_2$ to provide high yield and quality for blocky type pepper production. In the case of an open system, $N_2 + I_4$ proved to be the most efficient strategy.

Additional key words: *Capsicum annuum* L.; closed system; open system; substrate.

Resumen

Efectos de la nutrición y el riego en la producción de pimiento en toba volcánica

El objetivo de este estudio fue aumentar la sostenibilidad en un cultivo sin suelo, utilizando como sustrato toba volcánica y como material vegetal pimiento tipo rectangular (cv. 4-Ever F_1). Se evaluaron tres factores experimentales: sistema de cultivo (abierto o cerrado), composición de nutrientes (N_1, N_2, N_3, N_4) y frecuencia de riego (I_1, I_2, I_3, I_4). Las concentraciones N_2, N_3, y N_4de macro nutrientes fueron 2, 3 y 4 veces las de N_1, siendo las concentraciones de micronutrientes las mismas para todos los tratamientos. El riego se inició cuando la radiación solar bajo cubierta alcanzó 6, 4, 2 y 1 MJ m^2 en los tratamientos I_1, I_2, I_3 e I_4, respectivamente. Como técnica de cultivo sin suelo sostenible, en el sistema cerrado los tratamientos que proporcionan mayor rendimiento y calidad de pimiento son $N_4 + I_2$. En el caso de sistema abierto, la estrategia más eficiente es utilizar los tratamientos $N_2 + I_4$.

Palabras clave adicionales: *Capsicum annuum* L.; sistema abierto; sistema cerrado; sustrato.

Introduction

In soilless culture which is considered as a sustainable growing system, surplus nutrient solution causes environmental pollution if it is left to drain off. The amount of waste solution from 1 ha of soilless tomato culture per year is reported as high as 2,000 m^3 with 20% over-drain percentage by Benoit and Ceustermans (1995) and 2,900 m^3 with 15-25% over-drain percentage as estimated by Gül *et al*. (2003). Ferrante *et al*. (2000) indicate that about 93 N, 6.8 P, 165 K and 107 Ca kg ha^{-1} per year were released into the environment from gerbera (*Gerbera jamesonii* H. Bolus) production in substrates. With the increasing awareness of the environmental aspects, closed soilless systems have gained importance (Van Os, 2000; Schnitzler, 2004). The recycling of greenhouse effluents in closed systems enables a considerable reduction of fertilizer application and a drastic restriction or even a complete elimination of nutrient leaching from greenhouses to the environment. Also, closed systems improve in an economically viable manner the efficiency of water use in vegetable crops (Savvas, 2002). However, unsolved problems still exist. Re-use of drainage water leads to an accumulation of some nutrients and ballast ions, thus resulting in alterations in the nutrient ratios (Schröder and Leith, 2002).

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Turkey has nearly 36,000 ha greenhouse area, of which 96% is used for vegetables production. Soilless cultivation started on a commercial basis in the 1990's and total area is estimated as 244.5 ha in 2009. Growers prefer to use open systems due to their high adaptability to the farmers' conditions, but it is evident that switching over to closed systems is needed if potential environmental problems might be encountered in intensive greenhouse areas in the future. Although soilless cultivation techniques are generally used for tomato (*Solanum lycopersicum* L.) and blocky type pepper (*Capsicum annuum* L.) production at farmers' level, research on this topic is mainly focusing on tomato and cucumber production. Therefore, blocky type pepper was used as plant material in this study aimed to increase sustainability in soilless cultivation.

Material and methods

Plant material and greenhouse conditions

This study was conducted in an unheated polyethylene covered greenhouse during fall (August 22-December 26, 2002) and spring (March 12-July 10, 2003). The tested plant material was sweet pepper (*Capsicum annuum* L.), specifically the red-fruiting cultivar 4-Ever F_1, California type. Seedlings from a commercial nursery were transferred to the substrate with a plant density of 3 plants m^{-2} (90×37.5 cm) and 6 plants in each plot. Volcanic tuff, 65% of particles sized between 1 and 3 mm, was used as substrate with a volume of 10 L $plant^{-1}$.

Treatments

Experiments were designed according to the split-split plots design with 3 replicates. The experimental factors were as follows: (1) cultivation system (open or closed), (2) nutrient composition (N_1, N_2, N_3, N_4) and (3) irrigation frequency (I_1, I_2, I_3, I_4). The main plots were assigned to cultivation system, nutrient composition and irrigation frequency were established in sub and sub-sub plots, respectively. Each sub-sub plot had 6 plants.

Complete nutrient solution was used to cover water and nutrient requirements of the plants. The chemical composition of the nutrient solution used in the treatment N_1 was (mg L^{-1}): N 60, P 15, K 75, Mg 12.5, Fe 1.5, Mn 0.75, B 0.4, Zn 0.50, Cu 0.2 and Mo 0.03. Concentrations of macro nutrients excluding Ca in the treatments of N_2, N_3 and N_4 were 2, 3 and 4 fold those used in N_1. Since Ca content of irrigation water was 100 mg L^{-1}, no Ca was added in the treatment N_1; on the other hand 30, 60 and 90 mg L^{-1} Ca was added in the treatments N_2, N_3 and N_4, respectively. Micronutrients were applied at the same dose to all treatments. Irrigation timing was based on indoor integrated solar radiation, using light-sum levels of 6, 4, 2 and 1 MJ m^{-2} in the treatments I_1, I_2, I_3 and I_4, respectively. The amount of nutrient solution was adjusted according to keep a drainage volume between 20 and 30% of total supply.

In the treatments operated as open systems, plants were fed from the four different tanks (N_1, N_2, N_3, N_4) regardless of irrigation treatment, but drained water was collected into separate tanks (4 nutrient composition * 4 irrigation frequency = 16 tanks) from each treatment. In closed system, each treatment had its own tank (4*4 = 16) and make-up solution was added to maintain original volume.

Variables measured

Yield

Total and marketable yield as harvested fruit weight and number were recorded. Deformed fruits due to parthenocarpic or affected by blossom-end rot, were classified as unmarketable.

Water use efficiency

Water use efficiency (WUE) was determined in terms of kg of total fresh yield per m^3 of water supplied to the crop. Since all replications of each treatment had the same drainage tank, average WUE values were calculated for each treatment.

Fruit quality

Fruit samples were taken once in each production season in order to determine some fruit quality characteristics, namely diameter (cm), length (cm) and pericarp thickness (mm). Ten fruits were sampled from each treatment and analyzed for each quality characteristic.

Statistical analysis

The obtained data were subjected to analysis of variance. Effects of macronutrient composition were evaluated by trend comparisons. Since levels of irrigation frequencies were not equally spaced, Fisher's protected least significant difference (LSD) test at $p \leq 0.05$ were made to evaluate the effect of this treatment instead of trend comparisons.

Results

Yield

Autumn

The main effects of experimental factors ($p \leq 0.01$) and three-way interactions ($p \leq 0.01$) were significant in respect to total and marketable yields. Closed system led to decreased yield compared to open system, reductions averaged 17.2% and 18.4% in total and marketable yield, respectively. Percentage of marketable yield to total yield was determined as 95.2% in open system and 93.7% in closed system. In open system, total yield showed quadratic response to nutrient composition in I_1 and I_2, and cubic response in I_3 and I_4. In closed system, relation between total yield and nutrient composition was expressed with linear equation in I_1, I_2 and I_3, and cubic equation in I_4 (Fig. 1).

Regarding the harvested total and marketable fruit number, main effects of experimental factors and interaction between cultivation systems and nutrient concentrations were significant ($p \leq 0.01$). Number of fruits was higher in treatment N_2 in open system and N_4 in closed system. In the latter, a linear increase was detected with increased dose of nutrients (Fig. 2).

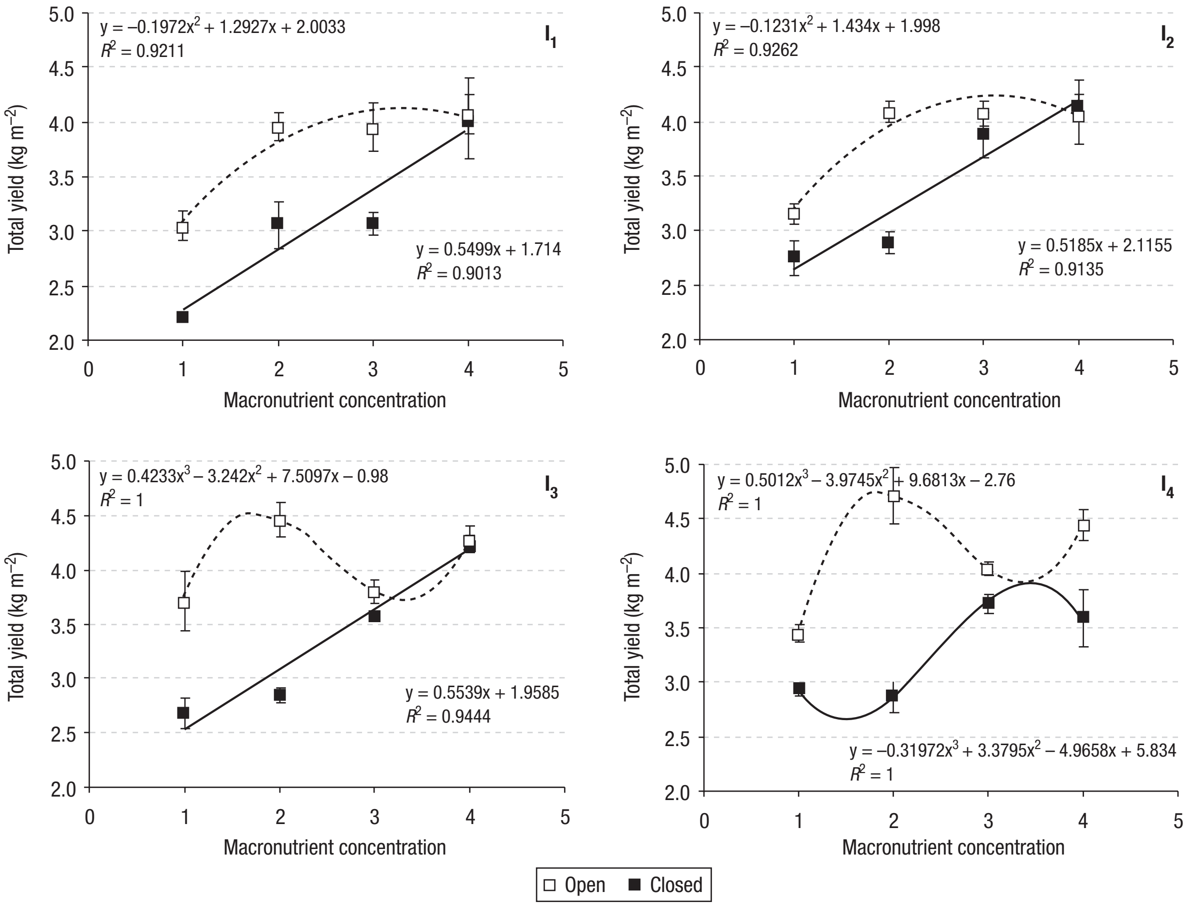

Figure 1. Response of total yield (kg m^{-2}) in an autumn crop of pepper grown by open or closed hydroponics to nutrient supply (basic and 2-, 3- or 4-fold increase of macronutrient concentrations, corresponding to N_1, N_2, N_3 and N_4, respectively) in different irrigation frequency (irrigation events triggered when solar radiation interception reached 6, 4, 2 or 1 MJ m^{-2}, corresponding to I_1, I_2, I_3 and I_4, respectively). Vertical bars indicate the standard error of means.

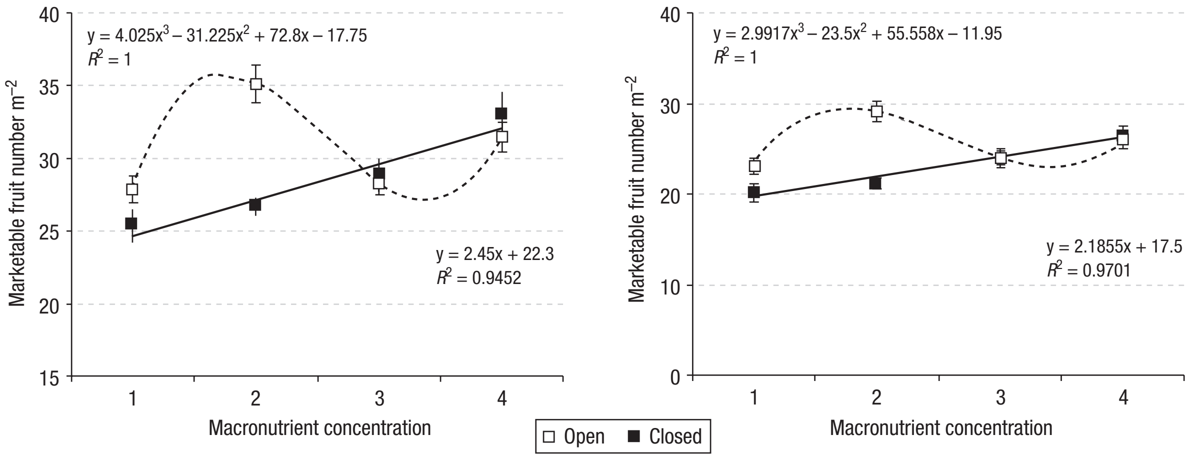

Figure 2. Response of total and marketable fruit number per square meter in an autumn crop of pepper grown by open or closed hydroponics to nutrient supply (basic and 2-, 3- or 4-fold increase of macronutrient concentrations, corresponding to N_1, N_2, N_3 and N_4, respectively). Vertical bars indicate the standard error of means.

Among the irrigation treatments, I_1 led to decreased fruit number (Fig. 3).

Spring

The main effects of experimental factors ($p \leq 0.01$) and two-way interactions (cultivation systems * nutrient concentrations and cultivation systems * irrigation frequencies) ($p \leq 0.01$) were significant in respect to total and marketable yields. In comparison to open system, closed system led to averagely 24.5 and 31.4% lower total and marketable yield, respectively. Ratio of marketable yield to total yield was 86.5% in open system and 78.5% in closed system. Total and marketable yield increased linearly with increasing nutrient concentrations in closed system. In open system, N_1 led to decreased total and marketable yields compared to the other nutrient concentration treatments, which gave similar values (Fig. 4). Interaction of cultivation systems * irrigation frequencies indicated that I_4 and I_2 resulted in higher total yields in open and closed systems, respectively. Regarding marketable yield, I_4 gave also higher values in open system, on the other hand there were no significant differences between irrigation treatments in closed systems (Fig. 5).

The main effects of cultivation systems ($p \leq 0.05$) and nutrient concentrations ($p \leq 0.01$) on the number of total and marketable fruits were significant. Two-way interactions of cultivation systems * nutrient concentrations and cultivation systems * irrigation frequencies were also significant ($p \leq 0.01$) in this

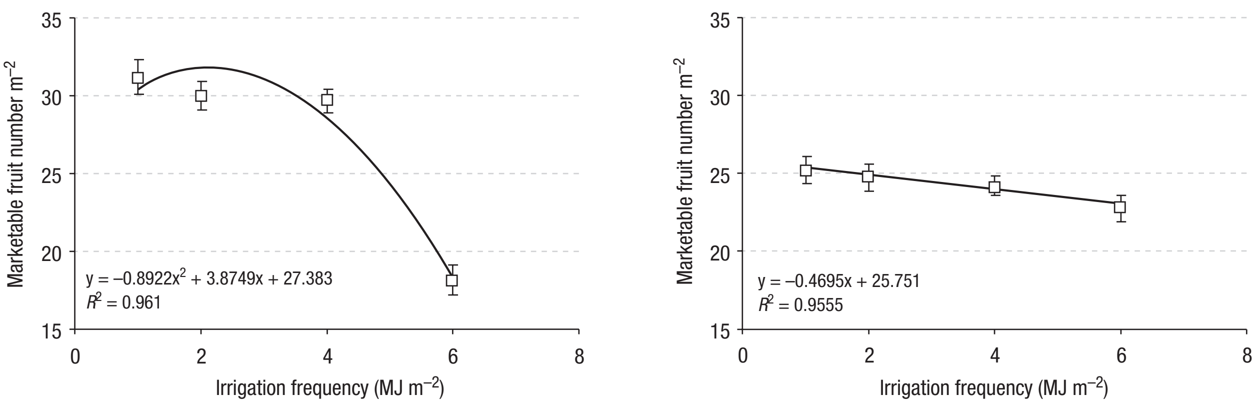

Figure 3. Response of total and marketable fruit number per square meter in an autumn crop of pepper to irrigation frequency (irrigation events triggered when solar radiation interception reached 6, 4, 2 or 1 MJ m^{-2}, corresponding to I_1, I_2, I_3 and I_4, respectively). Vertical bars indicate the standard error of means.

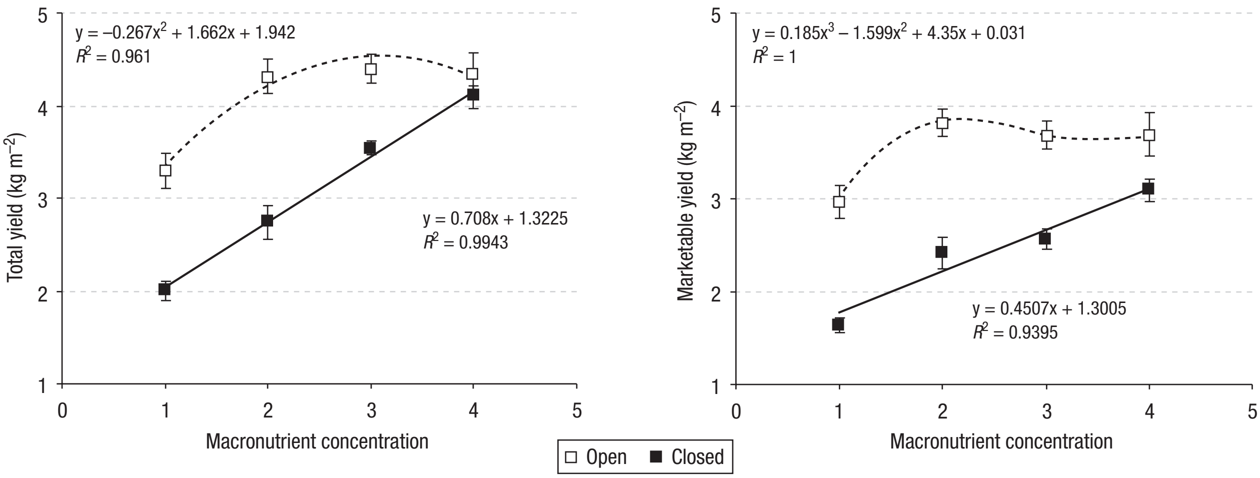

Figure 4. Response of total and marketable yield (kg m^{-2}) in a spring crop of pepper grown by open or closed hydroponics to nutrient supply (basic and 2-, 3- or 4-fold increase of macronutrient concentrations, corresponding to N_1, N_2, N_3 and N_4, respectively). Vertical bars indicate the standard error of means.

respect. Interaction between cultivation systems and nutrient concentrations was found that linear and quadratic regression curves were fitted to the numbers of fruits in closed and open systems, respectively (Fig. 6). Regarding the interactions of cultivation systems * irrigation frequencies, there were no significant differences between irrigation treatments in closed system, while I_4 led to higher fruit numbers in open system (Fig. 7).

Water use efficiency

Average WUE values are given in Table 1. WUE was increased in closed system compared to open system, and average increase amounted to 29% in autumn and 43% in spring season.

Fruit quality

Autumn

The main effects of experimental factors on fruit characteristics are shown in Table 2. There were no significant interactions in fruit quality between experimental factors. Cultivation system had a significant impact on fruit length ($p \leq 0.01$) which was higher in fruit from open system compared with closed system.

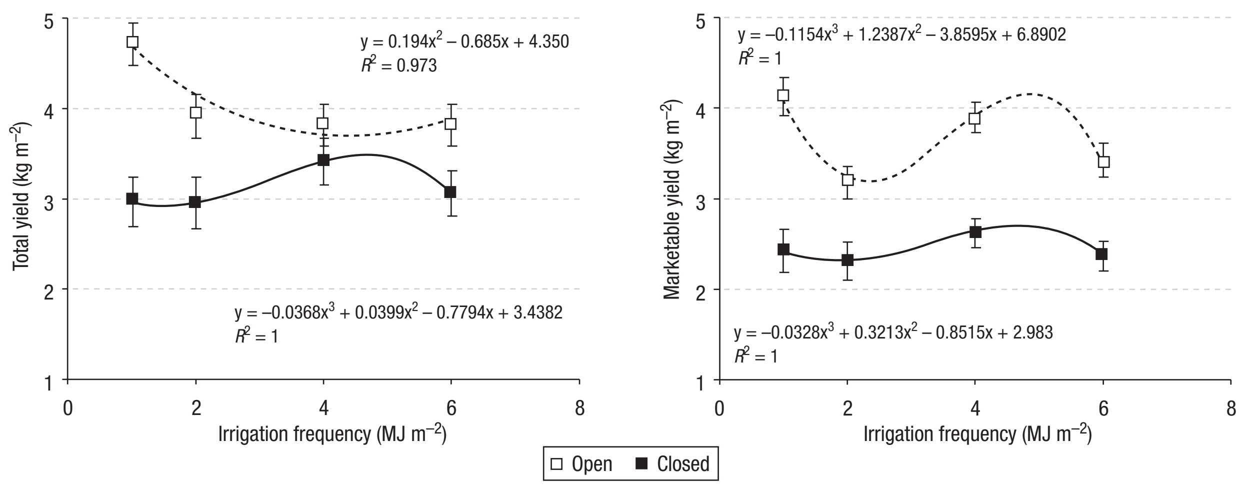

Figure 5. Response of total and marketable yield (kg m^{-2}) in a spring crop of pepper grown by open or closed hydroponics to irrigation frequency (irrigation events triggered when solar radiation interception reached 6, 4, 2 or 1 MJ m^{-2}, corresponding to I_1, I_2, I_3 and I_4, respectively). Vertical bars indicate the standard error of means.

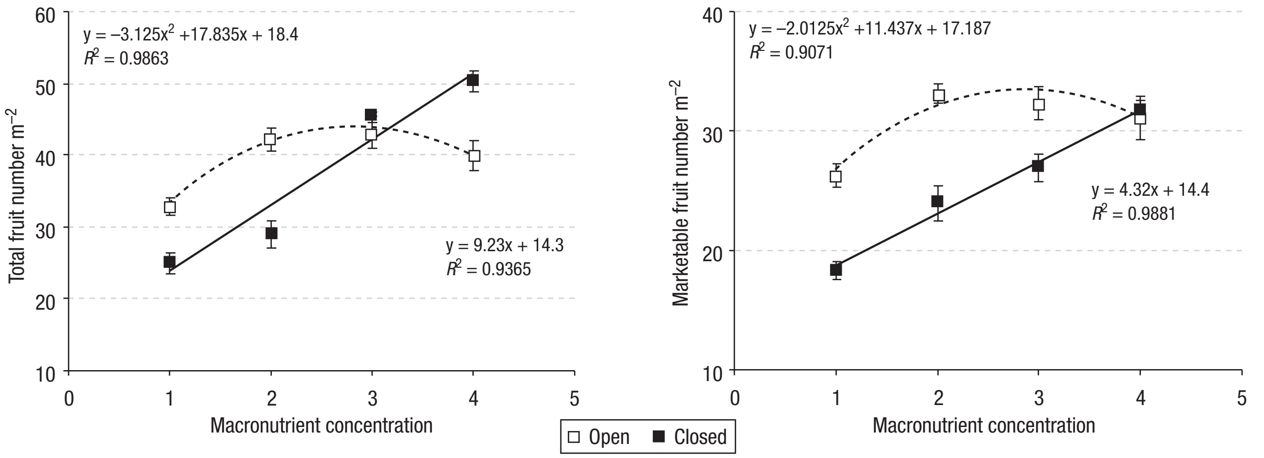

Figure 6. Response of total and marketable fruit number per m^2 in a spring crop of pepper grown by open or closed hydroponics to nutrient supply (basic and 2-, 3- or 4-fold increase of macronutrient concentrations, corresponding to N_1, N_2, N_3 and N_4, respectively). Vertical bars indicate the standard error of means.

Nutrient concentrations affected fruit diameter and pericarp thickness significantly ($p \leq 0.01$). The N_1 treatment decreased fruit diameter, while pericarp thickness increased by increasing concentrations of nutrients. Irrigation frequency had a significant impact on fruit diameter ($p \leq 0.05$) and pericarp thickness ($p \leq 0.01$). I_4 decreased fruit diameter, while pericarp thickness increased as irrigation frequency decreased.

Spring

The main effects of experimental factors on fruit characteristics are shown in Table 2. Interactions between experimental factors were not significant. Cultivation system had a significant impact on fruit diameter ($p \leq 0.01$), which was higher in open system compared with closed system. Nutrient concentrations affected significantly all quality characteristics ($p \leq 0.01$). Fruit diameter increased with the concentration of macronutrients, while lower nutrient levels enhanced fruit length. The N_1 treatment decreased pericarp thickness.

Discussion

Closed system led to lower total and marketable yield in both production seasons compared to open

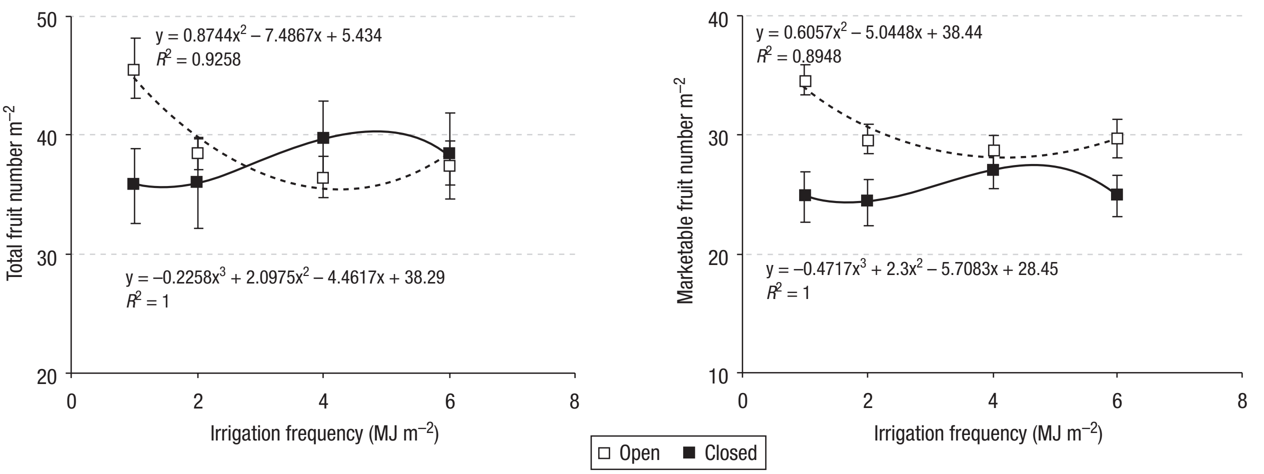

Figure 7. Response of total and marketable fruit number per m^2 in a spring crop of pepper to irrigation frequency (irrigation events triggered when solar radiation interception reached 6, 4, 2 or 1 MJ m^{-2}, corresponding to I_1, I_2, I_3 and I_4, respectively). Vertical bars indicate the standard error of means.

Table 1. Water use efficiency (kg m^{-3}) of pepper, as influenced by cultivation system (open or closed hydroponics), nutrient supply (basic and 2-, 3- or 4-fold increase of macronutrient concentrations, corresponding to N_1, N_2, N_3 and N_4, respectively) and irrigation frequency (irrigation events triggered when solar radiation interception reached 6, 4, 2 or 1 MJ m^{-2}, corresponding to I_1, I_2, I_3 and I_4, respectively)

Nutrient concentrations	Irrigation frequencies	Autumn		Spring	
		Open	Closed	Open	Closed
N_1	I_1	29.87	35.89	12.19	20.53
	I_2	27.85	35.57	10.85	17.75
	I_3	30.25	34.96	10.48	16.45
	I_4	26.54	35.00	13.29	16.45
N_2	I_1	28.97	34.95	12.35	18.88
	I_2	27.40	37.35	13.62	15.96
	I_3	26.55	36.07	11.71	16.01
	I_4	25.96	35.92	13.83	16.85
N_3	I_1	33.04	34.33	12.90	18.48
	I_2	30.93	37.95	13.01	17.83
	I_3	27.48	39.24	12.19	18.14
	I_4	27.63	39.24	13.10	17.48
N_4	I_1	30.09	37.19	14.51	20.81
	I_2	26.11	35.61	11.93	19.71
	I_3	27.55	33.23	12.59	19.33
	I_4	24.50	37.27	12.57	16.88
Mean		28.17	36.24	12.57	17.97

system, and this effect was more obvious in spring season. This result support a previous report of Schwarz and Kuchenbuch (1998) who found that high salinity under conditions of high solar radiation restricts water uptake and plant growth in hydroponics. Although there are several reports indicating that yield reduction may occur in closed systems, in most cases the extent of the differences depend on the growing conditions; *e.g.* growing season, nutrition or irrigation; and may be insignificant in some cases (Uronen, 1995; Willumsen, 1995; Böhme, 1996; Gül *et al.*, 1999, 2007; Ferrante *et al.*, 2000; Tüzel *et al.*, 2001, 2002; Meric, 2006).

Results obtained in the trials showed that the yield differences between open and closed systems tended to decreased with increasing nutrient levels in both seasons. In autumn, marketable yield reduction in the closed system compared with open system was determined as 22.4, 33.9, 10.9 and 6.4% in treatments N_1, N_2, N_3 and N_4, respectively. Similar results were obtained in spring season in this regard, and marketable yield was reduced in closed system compared to open system up to 44.8, 36.7, 30.4 and 16.2% as the nutrient supply increased from N_1 to N_4. The interactions between cultivation system and nutrient concentrations showed that treatments N_2 and N_4 provide the highest yield of blocky type pepper production in open and closed systems, respectively. These results support our previous findings that lower levels of nutrients were adequate in open system compared with closed system for tomato production in perlite (Gül *et al.*, 2007). It is reported that normal growth is possible when low nutrient concentrations are maintained continuously and never allowed to deplete (Adams, 1993). Ferrante *et al.* (2000), who compared different soilless growing systems, with and without nutrient solution recycling in gerbera pro-

Table 2. Fruit quality characteristics in an autumn or spring crop of pepper, as influenced by cultivation system (open or closed hydroponics), nutrient supply (basic and 2-, 3- or 4-fold increase of macronutrient concentrations, corresponding to N_1, N_2, N_3 and N_4, respectively) and irrigation frequency (irrigation events triggered when solar radiation interception reached 6, 4, 2 or 1 MJ m^{-2}, corresponding to I_1, I_2, I_3 and I_4, respectively). Values are the mean with the standard error

Treatments	Diameter (cm)		Length (cm)		Pericarp thickness (mm)	
	Autumn	Spring	Autumn	Spring	Autumn	Spring
Open	8.15 ± 0.058	8.60 ± 0.102	9.46 ± 0.071	7.78 ± 0.083	5.03 ± 0.080	5.40 ± 0.095
Closed	7.81 ± 0.064	7.92 ± 0.101	8.68 ± 0.074	7.59 ± 0.093	4.97 ± 0.103	4.90 ± 0.070
N_1	7.74 ± 0.069	7.96 ± 0.163	8.86 ± 0.095	7.89 ± 0.108	4.83 ± 0.120	4.80 ± 0.125
N_2	8.01 ± 0.050	8.11 ± 0.159	9.07 ± 0.084	7.82 ± 0.108	4.78 ± 0.099	5.10 ± 0.105
N_3	8.13 ± 0.059	8.32 ± 0.143	9.14 ± 0.105	7.41 ± 0.120	5.06 ± 0.107	5.30 ± 0.101
N_4	8.04 ± 0.077	8.65 ± 0.140	9.21 ± 0.115	7.62 ± 0.145	5.34 ± 0.150	5.30 ± 0.163
I_1	8.09 ± 0.057	8.25 ± 0.206	9.04 ± 0.098	7.73 ± 0.126	5.31 ± 0.120	5.00 ± 0.178
I_2	8.05 ± 0.097	8.20 ± 0.174	9.07 ± 0.104	7.58 ± 0.113	5.04 ± 0.122	5.10 ± 0.148
I_3	8.00 ± 0.080	8.27 ± 0.108	9.17 ± 0.156	7.71 ± 0.138	4.86 ± 0.113	5.00 ± 0.100
I_4	7.79 ± 0.065	8.32 ± 0.143	9.01 ± 0.108	7.71 ± 0.129	4.81 ± 0.139	5.30 ± 0.089

duction, also report on luxury consumption of nitrogen, phosphorus and potassium in open hydroponic systems.

Our results showed that application of larger amounts of water at longer intervals during the day gave better results in closed system. These results are in accordance with the findings of Meric (2006) who tested irrigation programs based on indoor solar radiation levels (1.0, 2.0 and 4.0 MJ m^{-2}) in tomato production. This effect may be attributed to decrease of the osmotic potential in the rhizosphere due to the movement of salts in the case of application of larger amounts of water.

Increasing WUE in closed system have been reported by several authors (Vernooij, 1992; Van Os, 1995, 1999; Marfa, 1999; Tüzel *et al*., 1999, 2001, 2002; Tüzel and Meric, 2001; Gül *et al*., 2003, 2007; Meric, 2006). Results obtained in this study are in accordance with the previous reports.

Our results showed that fruit quality of sweet peppers grown in substrates depended on both nutrition and irrigation. Open system gave better results than closed system with respect to some fruit characteristics. This effect could be attributed to nutritional imbalances in closed system. Among the nutrient concentrations N_1 was not adequate to provide a balanced nutrient supply and this had a negative impact on fruit quality. In autumn, fruit external diameter which is the most common quality trait used in commercial grading of pepper fruit, decreased significantly when irrigation frequency was set to 1 MJ m^{-2} solar radiation interception. A similar trend was observed also with respect to pericarp thickness. Overall, our results showed that decreasing irrigation frequency improved sweet pepper fruit quality under low solar radiation levels.

Unmarketable yield consisted mainly of deformed parthenocarpic fruits, caused by low temperatures, while the occurrence of blossom-end rot was negligible. Ratio of marketable yield was lower in spring compared to autumn season. This is reasonable, since the inside temperatures recorded during the period of fruit setting were higher in the autumn trial. Negative effects of low temperatures on fruit set and fruit size of sweet peppers have been well documented. Warm night temperature (15-20°C) is essential for normal flower development and formation of well-shaped pepper fruit (Rylski, 1973; Rylski and Aloni, 1994; Pressman *et al*., 1998).

Our results showed that closed hydroponic systems could be used for sweet pepper production without yield and quality losses if nutrition which is the major factor influencing the success, is properly managed. It was concluded that appropriate macronutrient concentrations in the nutrient solution supplied to closed-cycle hydroponic crops of pepper are as follows (mg L^{-1}): 240 N, 60 P, 300 K, 190 Ca, and 50 Mg; and irrigation timing can be based on indoor integrated solar radiation level of 4 MJ m^{-2}. In the case of open system, lower nutrient levels (120 N, 30 P, 150 K, 130 Ca, 25 Mg mg L^{-1}) compared with closed system were found to be adequate, and irrigation events can be initiated when indoor integrated solar radiation level reaches 1 MJ m^{-2}.

Acknowledgements

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